# Session 7: A REVIEW OF INTERNATIONAL FIRE RISK PREDICTION METHODS

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## *Introduction*

Over the decade of the 1980's, computer models and other predictive methods were increasingly applied to a broad range of practical problems in fire safety. Experience gained in this way showed that careful treatment of complex problems resulted in more consistant and defensible solutions than relying solely on expert judgement. Further, uncertainties in the models' predictions were no greater than those associated with the traditional, but much more expensive full-scale experimental studies Separate, multi-year research projects in Japan and the United States resulted in the publication of prototype fire hazard analysis systems which demonstrated the ability to account for the complex interactions of the fire, building, active protection systems, occupant actions, and detailed outcomes including damage estimates and fatality counts.

With the growing confidence in their ability, researchers in the U.S., Japan, Australia, Canada, and the United Kingdom began to develop detailed methodologies which could be used to evaluate the safety (and thus the code equivalency) of innovative building designs. In each case the goal was the same; to improve the flexibility and thus the cost effectiveness of new construction while not sacrificing public safety. Initially, these methodologies will supplement the existing codes and are expected to be used in only a small fraction of construction projects employing novel materials or arrangements. However it is recognized that success in these limited applications will lead eventually to performance based codes for general use. A critical aspect to performance based fire codes is the specification of design fires against which fire safety can be evaluated. The selection of such design fires should be based on the risk they pose including both severity and likelihood of occurrence.

As these developing methodologies were presented in the technical literature the author was struck with the similarities in approach. Further, each of the methodologies include techniques to address factors which the others have overlooked or treated less rigorously.

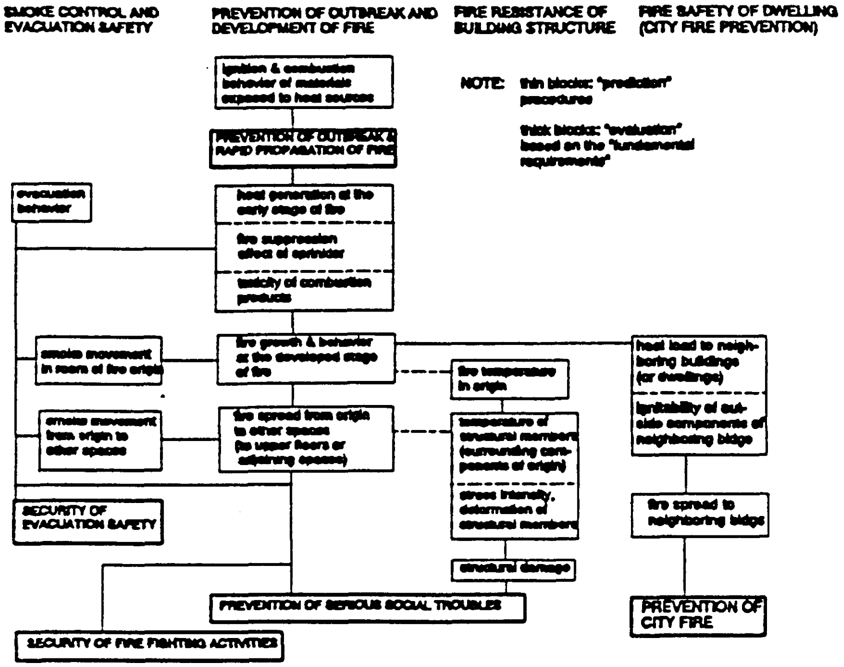


**Figure 1 - Schematic *diagram* of the structure of the Japanese evaluation procedure.**

Thus a number of key figures in the fire research community have suggested that, if a collaboration were established under the auspices of a body like the International Council of Building Research, Committee on Fire (CIB W14), a consistent methodology could be developed with a broad, multi-national acceptability.

To support this goal the author has prepared a comparison of the current methodologies to illustrate the similarities of approach and to identify those areas where the author feels each method can contribute the most toward a single, common system.

## *Current Fire Risk Assessment Methods*

Three methodologies have been described in the literature, two that are intended for the comprehensive evaluation of the fire safety performance of building designs and one for products that go into buildings. The former are a Japanese system developed by the Ministry of Construction and an Australian system developed by a National task force as part of a regulatory reform program. The latter is a U.S. methodology developed by a public/private consortium and published by the National Fire Protection Research Foundation. It is these three methods which are the principal focus of this paper. Although originally developed with a different focus, the U.S. method contains all of the same functions of the other two and can be used in the same way.

In 1982, the Japanese instituted a five year development project titled *Fire Safety Design* Method of Buildings with the goal, " ... to provide building designers with a design method of fire safety for buildings usable as an alternative to the Building Standard Law and its associated orders .... [1]. The resulting analytical method was published in a four volume report [2] in December of 1988. Once published, the method was available for use, and has been applied in a number of unique projects ranging from a new Sumo wrestling stadium in Tokyo [3] to the new Osaka International Airport [4]. A flowchart of this method is shown in figure 1 [5].

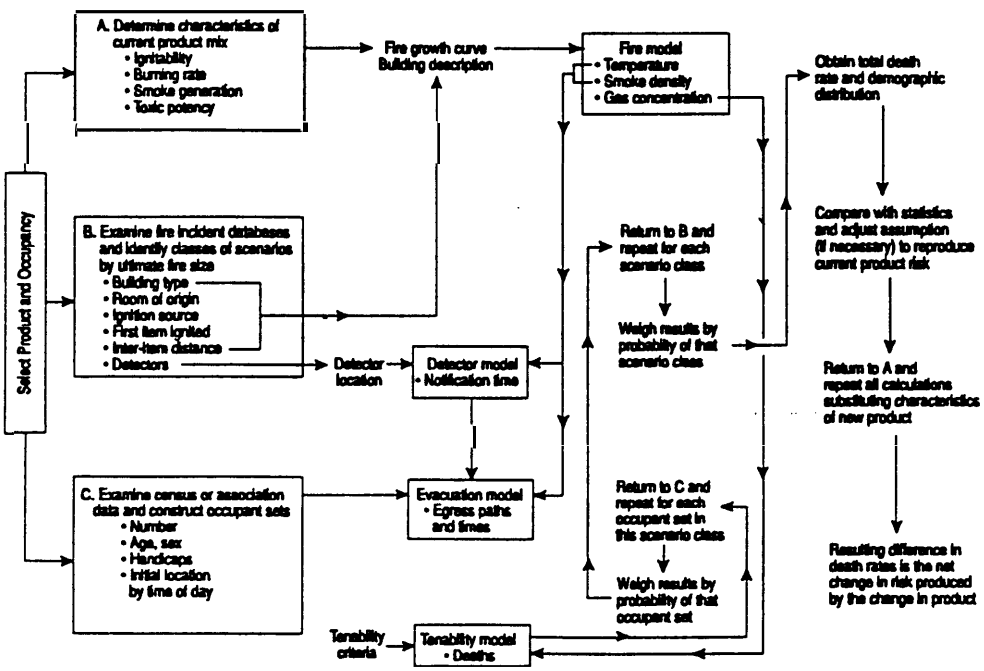


**Figure 2 - Modeling sequence to compute fire risk in the US method.**

In 1986, the National Fire Protection Research Foundation (NFPRF) instituted the National Fire Risk Assessment Project with the goal of " ... developing an objective, comprehensive, generally applicable and widely recognized fire risk assessment methodology for products that go into buildings." The work was a collaborative effort of the National Institute of Standards and Technology (NIST), the National Fire Protection Association (NFPA), and Benjamin/Clarke Associates. While tailored to the quantification of the fire risk associated with a specific class of products in a specified occupancy, it can also be used to assess general fire risk of a specified building design. It considers the same, comprehensive list of factors as the Japanese and Australian systems, and has been implemented in a software system which handles much of the computational burden.

The NFPRF methodology is documented in seven reports There is a project report [6], description of the computational method [7], four case study reports [8], and documentation for the software system [9]. In this system, the software implementation goes far beyond the computer models which form a part of the other methods. Lists of fires of interest in different spaces along with distributions of occupant groups can be specified such that the large number of fire scenarios needed to quantify the risk (in case study no. 1, approximately 120,000 scenarios were examined) are run automatically, weighted by the associated probability, and the final risk, along with demographic analysis of losses by category using categories common in incident data reporting, are generated. A flowchart of this methodology is presented in figure 2 [7].

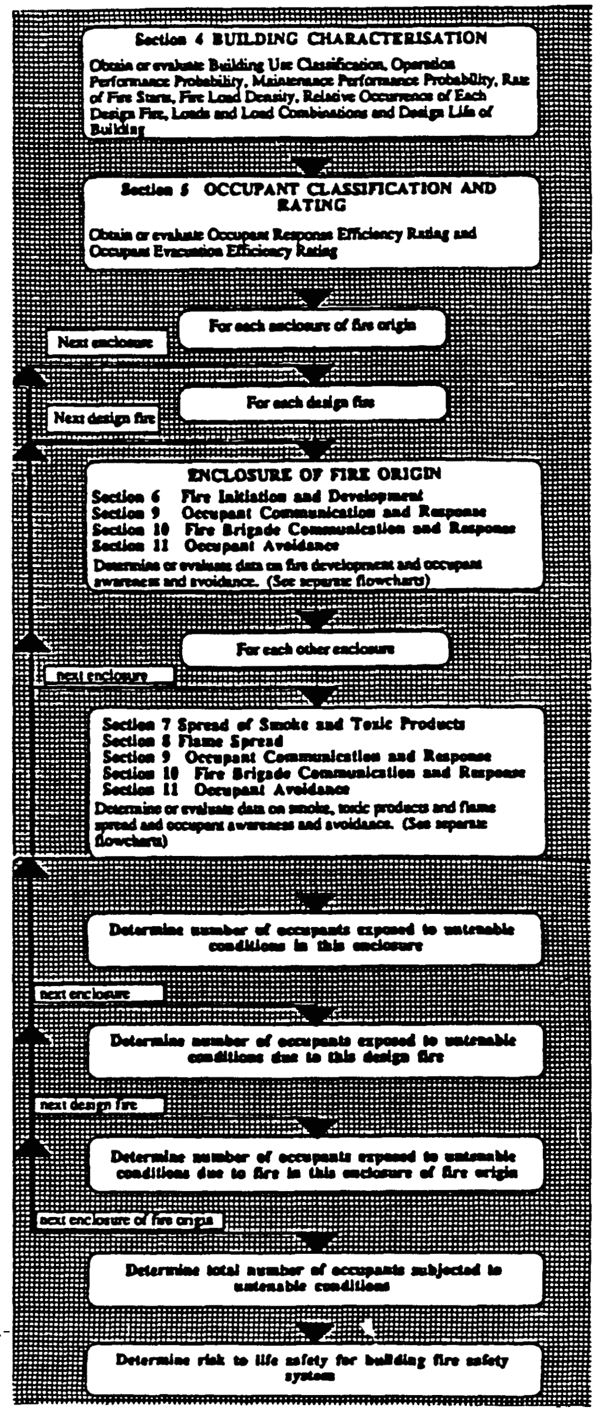


Figure 3 - Flowchart of simplified risk assessment used in the Australian method.

The Australian method is the product of a broad, national program to streamline building regulations The technical foundation was laid at an international conference organized by the Warren Center of the University of Sydney in 1989 which brought together the best experts in Australia and invited persons from around the world. Papers presented at the conference were published in a proceedings [IO] and the reports of eight task groups along with example case studies were published in two volumes [11].

Following the Warren Center conference work on a methodology was undertaken under the Building Fire Safety Systems Project by the Building Regulation Review Task Force which published a draft regulation for international review and comment [12]. The complete methodology is presented, however most numerical values needed to apply the method to actual problems have yet to be decided by committees of experts convened for the purpose. The Canadian government through the National Research Council has been working closely with the Australians developing this method, and are committed to its acceptance in Canada [13]. A flowchart of this method is presented in figure 3 [12].

These independently developed fire risk assessment methods use remarkably similar approaches. In fact, an analysis performed under one method would likely satisfy the requirements of the other two with little change, other than where one system treats a topic which the others do not treat. Each method incorporates features from which the others could benefit. Thus, the obvious conclusion is to collaborate on an international method which exploits the best of each and which represents a universal approach to building fire safety analysis.

## *Measures of Fire Safety Performance*

The fundamental point of unanimity is that the methodology must evaluate the *perceived* fire risk associated with the building both in ordinary use and during reasonably expected events. This means that a building located in an earthquake zone would be safe from the range of fires expected in normal use and those which might follow a major earthquake However, one might not necessarily expect a building to be able to withstand the impact of an airplane loaded with fuel, even though such have happened at least twice in the U.S. In general, the risks against which buildings are designed would vary at least by location and occupancy classification.

By its classical definition, risk incorporates a measure of the magnitude of hazard posed by an event and the likelihood that the event will occur. In fire risk, the former is generally expressed as life loss, injury, or property damage, and the latter as the frequency of the specific hazard scenario. These concepts are universally applied in the methodologies reviewed for this paper. In each case the methods account for every fire scenario of importance to the overall risk, ranging from those common situations with minimum losses to catastrophic but (hopefully) infrequent events There is a clear preference to derive these scenarios and their associated probabilities from fire incident databases, but everyone recognizes the limitations of these data bases and allows for probabilities *suggested* by panels of experts.

Each of these risk assessment systems then works in the same way. A set of fire scenarios of interest is identified, accounting for the materials, arrangements, and activities expected in the building as a function of its use (i.e., by *occupancy class* as is traditional in *codes).* Sets of these fires are posited in each room of the building. Similarity allows the final number of runs to be minimized although large, mixed occupancies such as hotels might require very large numbers of calculations Predicted losses are multiplied by the probability of the scenario and the results tallied across all scenarios. The result is an expected risk of death (or injury or property damage) by fire for the building.

A final common point is that all of these risk methods (currently) avoid the question of what *is an acceptable* level *of risk.* Rather than try to set an absolute risk limit, each states that the predicted risk cannot be greater than that associated with a building of similar size and use, built to comply with the current prescriptive code. Of course, since these are new methods and have not been applied to any existing buildings, the code implied risk is not known. The baseline risk for code complying buildings is presumed to represent the risk that society will accept.

Where the methods differ is in the level of detail included. Specifically, each of the methods proposed to date deal with the major issues, usually in the same ways; but some have developed treatments for secondary factors which the others ignore. These issues and the ways in which they are addressed will be presented in the next sections of this paper.

## *Comparison of the Methods*

### STEP 1: CLASSIFY THE BUILDING AND ITS OCCUPANTS

All building and fire codes categorize buildings by their end use, called the occupancy. Typical occupancies found in most codes include residential, mercantile, storage, health care, etc. This use classification has evolved as the most useful in suggesting such diverse characteristics as building construction, room sizes, fuel load and type of combustibles, occupant characteristics and typical activities

In each of these risk methods, the purpose of the analysis is to compare the risk with that for buildings of the same use (occupancy) built in compliance to the prescriptive code. In the Japanese and Australian methods the typical occupancy classes are listed in tables which give assumed values for fire loads and material characteristics, fire incidence rates, occupant load and characteristics, and other parameters needed to define the set of fire scenarios against which the building design must protect. These data are derived from the consensus opinion of expert groups In the U.S. system the first choice for such data is survey information from governmental sources (e.g., Census surveys and fire department reports) or trade associations (e.g, the Hotel/Motel Association has detailed descriptions of typical hotel room contents and demographics of hotel guests, both as a function of the price category of the property). If such data are not available, the fallback source is expert opinion.

### STEP 2: QUANTIFY THE DESIGN FIRES

In each of the methods the design fires represent the challenge that the building is designed to withstand. They are intended to be representative (rather than worst case) of the fires which would be expected, given the room use, contents, and occupant activities Each of the methods makes use of the observation that the burning rate, Q of most objects can be approximated by an exponential growth curve of the Form $Q=\alpha t^2$ (where $\alpha$ varies as a function of the materials involved), leveling off at a constant value controlled by fuel load or ventilation, and burning out when the fuel is exhausted. The major variation is in the selection of the growth coefficient, $\alpha$. To account for toxicity, each system specifies a generic production rate for CO and $CO_2$, and the Japanese and U.S. methods allow for these rates to vary to account for differences in the toxic potency of materials.

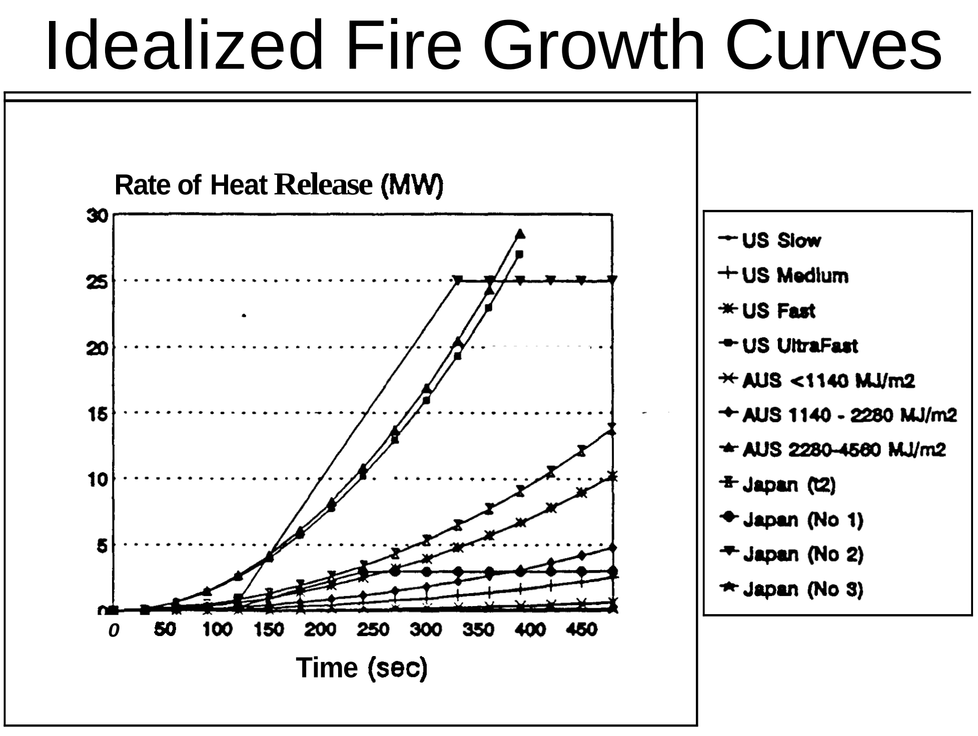


**Figure 4 -** Comparison of **the** basic **fire growth *curves* specified** in **the three methods**

The Japanese primarily use fire growth curves derived from correlations to experimental data. Curves are provided to be applied in spaces of differing area and fuel characteristics, with a limiting peak value as a function of room height. Both linear and exponential growth curves are discussed. Ventilation arrangements are assumed to be the most likely to be encountered. The effects of ventilation on limiting the burning rate are addressed in the model used for fire growth and spread.

The U.S system uses data on materials first ignited from incident databases to identify product/material inventories in the rooms. These are then categorized into one of three exponential growth curves (slow, medium, or fast) and one of three peak values (law, medium, or high). Thus, the universe of possible fire growth curves is limited to nine. Burnout times are computed from fuel loads. Ventilation effects on burning are accounted for in the fire model and the calculation can account for the probability that a specific door or window might be open or closed (if such a probability can be assigned).

The Australian method calls for evaluating a smoldering, pre-flashover, and post-flashover fire in each space. For each, a peak value is specified; for the flaming fires the peak is 75% and 100% of the rate of heat release needed for flashover using Thomas' equation [14]. Peak values can be limited by ventilation and by the presence of automatic suppression. One of three a values are specified as a function of fuel load and then modified by a series of multipliers to account for controls on materials. Burnout times are computed from fuel loads but can be modified for ventilation. In accounting for many more variables, the Australian system must compute many more scenarios. A comparison of the basic fire growth curves is presented in figure 4.

### STEP 3: PREDICT SMOKE AND GAS SPREAD

In the first two steps, the parameters which define the set of fire scenarios of concern are established. Each of the methods then set out to predict the outcome of each of the scenarios using computer models or other predictive methods Each recognizes the fire models FIRST [15] and FAST [16], and the Japanese cite BRI2 (ref [17] describes an earlier version of this model and is the only version with an English language reference). The Japanese also describe a simple, hand calculation procedure (single-zone, fully stirred) and each recognizes other "appropriate' computational methods

### STEP 4: PREDICT THE RESPONSE OF OCCUPANTS

The Japanese and Australian methods tabulate occupant loads, locations, activities (asleep or awake), and characteristics by occupancy. Both then tabulate a series of delay times for alerting, decision making, investigation, fire fighting, assisting others, etc., and movement speeds, all to be used in computing evacuation times required. The U.S. system gives the option of using an evacuation model (EXITT [18]) where appropriate, or the same procedure cited in the Australian method.

The major difference in this area is in evaluating the effect of occupant exposure during egress. In the Japanese and Australian methods, simple limiting values for temperature and toxic gas exposure are cited. If these values are exceeded in inhabited spaces, the occupants are counted as fatalities. In the U.S. method, a more elaborate tenability model, TENAB [19] which accounts for time dependent dose-response is used.

### STEP 5: PREDICT INTERVENTION (BY FIRE BRIGADE OR OTHERS)

In the Japanese system the ability of the protection systems to maintain safe areas from which the fire department can operate is assessed, but their impact on the fire or on rescuing occupants is not.
The Australians predict the time that the fire department will begin suppression operations Factors considered include automatic notification (alarm system), travel and set up time (urban or rural department), and a performance level (training, staffing, equipment, etc.). They are successful if they begin suppression before a critical fire size is reached. They also give limited credit for occupants' use of first-aid fire fighting equipment if provided, by modifying the probability that the fire will be suppressed before flashover.

The U.S. system is a bit more complex. In step 2, fire incident data is used to identify items first ignited and, from them, growth rates and peak release rates. These same incident data will indicate that many of the fires do not reach a size (extent of flame spread category) consistent with this item first ignited. For example with a sofa as the first item ignited one would expect that it would flash over most rooms. However the incident data show some number of fires where the flame was limited to the first item ignited. The method considers these as incidents in which some intervention (by occupants, fire department, or sprinklers) took place.

STEP 6: OUTCOME PREDICTION (VARIES WITH METHOD)

The last step in the analysis is different for each method. In the Japanese system the potential for fire spread from floor to floor up the outside of the building is evaluated along with the potential for spread to adjacent buildings. The method also predicts the potential for structural collapse due to thermal stress on bearing components. These calculations relate to existing requirements in the Japanese Code.

In the Australian method the predicted outcomes are modified for a number of subjective factors including construction quality, frequency and reliability of testing and maintenance, staff training, or contracting services to qualified persons These are in the general form of an evaluation system table with modifying factors reflecting the effect on reliability In the U.S. method, the reliability of protective measures is explicitly addressed in the performance prediction.

The last step in the US method is to validate the predicted outcomes by comparing the predicted results against incident statistics That is, predicted losses for buildings designed to the current code should replicate observed losses for those buildings. This step establishes a confidence level in the result, but requires incident data not available in Japan or Australia.

## *The Need for Collaboration*

We now have three independently developed but highly compatible fire risk prediction methodologies. Each incorporates features which are significant advances in the state-of-the-art and from which the others could benefit. For example, the Japanese have developed the means to evaluate fire spread beyond the floor of origin and structural impact crucial to the application of such analyses to large buildings. The U.S. has developed the means to incorporate incident data which makes the result more representative and allows some validation. The Australians have developed the means to address a large number of subjective factors which can have a significant impact on the observed performance of buildings but are difficult to treat quantitatively.

Thus, it is clear that a collaboration which results in a single, composite methodology which fully exploits the advances made by each country is called for. Further, significant interest by the world's fire research community should result in additional collaborators and further improvements. That is why this collaboration should be organized under the auspices of an international body such as CIB W14.

## *The Resulting Benefits*

The resulting methodology 'would be suitable for international standardization through ISO. The existence of an internationally standardized method for building fire safety analysis will not only be of substantial benefit to individual countries, but may also have an impact on the reduction of trade barriers in the international design and construction industries

Such a standard analytical tool could also Serve as the foundation of the transition to true Performance Codes. As discussed in a recent paper, Bukowski and Tanaka [20] lay out a strategy for such a code. Key to this strategy is an analytical framework which can be used to quantify the level of performance that now can only be implied from prescriptive requirements. Only after such quantification in a consistent set of terms can the process of rationalization (both nationally and internationally) be achieved.

Advances in fire science over the past two decades are beginning to form the common thread that will bring together disparate cultures with vastly different histories in a way seldom imagined, much less realized. We must take advantage of this opportunity

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